Appendix A

<u>Donald G. Fink & H. Wayne Beaty, Standard Handbook for Electrical Engineers</u>, 12th Edition, pages 2-19, 2-20.

or

$$\text{At/in} = 0.3133\, B \qquad \text{lines/in}^3 \tag{2-64}$$

The ampere-turns for each portion of iron, computed from iron magnetization curves such as Fig. 2-7, and the ampere-turns for the air gaps are added together to give the ampere-turns for the complete magnetic circuit.

60. Analysis of Magnetization Curve. Three parts are distinguished in a magnetization curve (Fig. 2-7): the lower, or nearly straight, part; the middle part, called the knee of the curve; and the upper part, which is nearly a straight line. As the magnetic intensity increases, the corresponding flux density increases more and more slowly, and the iron is said to approach saturation (see Sec. 4).

61. Magnetization per Unit Volume and Susceptibility. If a portion of ferromagnetic material is magnetized by an mmf, H At/m, the resulting flux density in teslas may be written as

$$B = \mu_0(H + M) \tag{2-65}$$

where M is the magnetization per unit volume of the material (see Sec. 4).

The ratio of M/H is symbolized by χ and is called the *magnetic susceptibility*. It is the excess of the ratio of $B/\mu_0 H$ above unity, that is,

$$\chi = \frac{B}{\mu_0 H} - 1 \tag{2-66}$$

This is a dimensionless quantity. See Sec. 1.

62. The Right-Handed-Screw Rule. The direction of the flux produced by a given current is determined as shown in Fig. 2-8 (see also Fig. 2-6). If the current is established in the direction of rotation of a right-handed screw, the flux is in the direction of the progressive movement of the screw. If the current in a straight conductor is in the direction of the progressive motion of a right-handed screw, then the flux encircles this conductor in the direction in which the screw must be rotated in order to produce this motion. The dots in the figure indicate the direction of flux or current toward the reader; the crosses, that away from him.

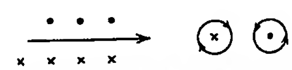

FIG. 2-8 Relation between directions of current and flux.

63. Fleming's Rules. The relative direction of flux, emf, and motion in a revolving-armature generator may be determined with the right hand by placing the thumb, index, and middle fingers so as to form the three axes of a coordinate system and pointing the index finger in the direction of the flux (north to south) and the thumb in the direction of motion; the middle finger will give the direction of the generated emf (Fig. 2-9). In the same way, in a revolving-armature motor, by using the left hand and pointing the index finger in the direction of the flux and the middle finger in the direction of the current in the armature conductor, the thumb will indicate the direction of the force and, therefore, the resulting motion. These two rules, indicated in Fig. 2-9, are known as Fleming's rules.

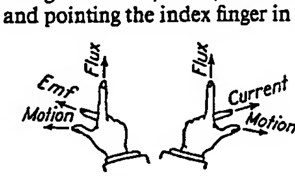

FIG. 2-9 Fleming's generator and motor rules.

64. Magnetic Tractive Force. The attracting force of a magnet is

$$F = \frac{1}{2}\frac{AB^2}{\mu_0} = \frac{AB^2}{8\pi \times 10^{-7}} \qquad \text{newtons} \tag{2-67}$$

where B is the flux density in the air gap expressed in teslas (webers per square meter) and A is the total area of the contact between the armature and the core, in square meters. The mass that can be supported is dependent upon the gravity field in which the mass and magnet are located.

65. Magnetic Force, or Torque. The mechanical force, or the torque, between two parts of a magnetic or electric circuit may in some cases be conveniently calculated by making use of the principle of *virtual displacements*. An infinitesimal displacement between the two parts is

assumed. The energy supplied from the source of current is then equal to the mechanical energy for producing the motion, plus the change in the stored magnetic energy, plus the energy for resistance loss.

When the differential motion ds m of a part of a circuit carrying a current I A changes its self-inductance by a differential dL H, the mechanical force on that part of the circuit, in the direction of the motion, is

$$F = \frac{1}{2} I^2 \frac{dL}{ds} \qquad \text{newtons} \tag{2-68}$$

When the motion of one coil or circuit carrying a current I_1 A changes its mutual inductance by a differential dM H with respect to another coil or circuit carrying a current I_2 A, the mechanical force on each coil or circuit, in the direction of the motion, is

$$F = I_1 I_2 \frac{dM}{ds} \qquad \text{newtons} \tag{2-69}$$

where ds represents the differential of distance in meters. For a discussion of self- and mutual inductance L and M see Pars. 77 and 85.

Hysteresis and Eddy Currents in Iron

66. The Hysteresis Loop. When a sample of iron or steel is subjected to an alternating magnetization, the relation between B and H is different for increasing and decreasing values of the magnetic intensity (Fig. 2-10). This phenomenon is due to irreversible processes which

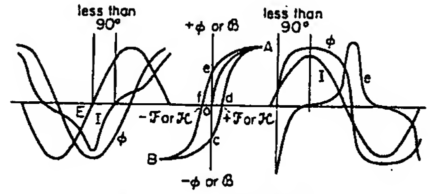

FIG. 2-10 Periodic waves of current, flux, and emf; hysteresis loop.

result in energy dissipation, producing heat. Each time the current wave completes a cycle, the magnetic flux wave must also complete a cycle, and the elementary magnets are turned. The figure *AefBcdA* in Fig. 2-10 is called the *hysteresis loop.*

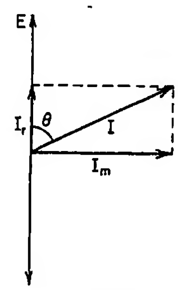

FIG. 2-11 Components of exciting current; hysteretic angle.

67. Retentivity. If the coil shown in Fig. 2-6 is excited with alternating current, the ampere-turns and consequently the mmf will, at any instant, be proportional to the instantaneous value of the exciting current. Plotting a B-H (or ϕ-$\mathcal{F}$) curve (Fig. 2-10) for one cycle, the closed loop *AefBcdA* is obtained. The first time the iron is magnetized, the *virgin,* or *neutral, curve OA* will be produced; but it cannot be produced in the reverse direction *AO*, because when the mmf drops to zero there will always be some remaining magnetism ($+Oe$ or $-Oc$). This is called *residual magnetism;* to reduce this to zero, an mmf ($-Of$ or $+Od$) of opposite polarity must be applied. This mmf is called the *coercive force.*

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